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Technical Note N-932

EFFECT OF EXPOSURE ANGLE ON THE ATMOSPHERIC PERFORMANCE OF COATINGS.

I. RESULTS OF TWO-YEAR EXPOSURES

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Peter J. Hearst, Ph. D., and C. V. Brouillette

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Internal Working Paper

NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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ABSTRACT

In tropical locations, the solar radiation received by a test panel can be considerably increased by changing the exposure angle from 45° to the angle of the latitude. Results of two-year exposures at 45° and at 9° at Kwajalein, Marshall Islands, of scribed and unscribed panels coated with zinc inorganic silicates and organic topcoat systems are compared. The 9° exposure may be more severe as judged from the protective properties of the coatings, but the results are not conclusive over this limited period of time.

INTRODUCTION

The U. S. Naval Civil Engineering Laboratory (NCEL) evaluates new coatings for the protection of steel structures exposed to a marine atmospheric environment. Especially for some of the newer coatings which afford very good protection, such evaluations may require many years. If the time required for such evaluations could be reduced by even a small factor, considerable savings could be realized not only by the Naval Facilities Engineering Command but also by many other government and private organizations that evaluate new coatings for atmospheric exposure.

Reliable accelerated laboratory methods, that would speed the determination of the performance of new coatings or coating systems, are not available. Work is presently in progress at NCEL to develop better accelerated methods for testing coatings in the laboratory. This work includes accelerated weathering studies and degradation studies of coating films.

Because reliable laboratory tests are not available, it was decided to investigate the possibility of a more rapid determination of the relative performance of coatings in a natural environment. In previous marine atmospheric exposures of coating systems at Port Hueneme, California, at Kaneohe, in the Hawaiian Islands, and at Kwajalein, in the Marshall Islands, the deterioration increased in this order with very few exceptions; that is, the most rapid deterioration occurred in the most tropical area. The chief atmospheric factors are probably the salt spray, the high humidity, and the solar radiation.

By simply decreasing the usual exposure angle of panels exposed in a tropical environment, that is, by exposing them in a more nearly horizontal position, the amount of solar radiation received can be increased. It may thus be possible to increase the rate of deterioration and to decrease the time required to determine coating performance.

The comparative performance of a variety of coated panels exposed at 45^{o} from the horizontal and at 9^{o} from the horizontal at Kwajalein has been observed for two years, and the results are discussed in this report.

METHODS AND RESULTS

Steel panels covered with 21 coating systems were exposed at Kwajalein, in the Marshall Islands, on racks tilted at 45^{o} from the horizontal and facing approximately eastnortheast into the surf. A second identical set of panels was exposed on racks tilted at 9^{o} from the horizontal and facing south, as shown in Figure 1.

The coating systems consisted of four different zinc inorganic silicate coatings which were exposed without topcoats or were covered with four different topcoat systems. The zinc inorganic silicate coatings were either post-cured or self-cured, as shown below. The topcoats consisted of the four military specification coating systems shown below, generally applied over an intermediate coat of pretreatment primer (MIL-P-15328B):

Primer Coating

1. Zinc inorganic silicate, post-cured
2. Zinc inorganic silicate, self-cured
3. Zinc inorganic silicate, self-cured
4. Zinc inorganic silicate, post-cured

Topcoat Systems

A. Alkyd enamel system (TT-E-489c, Class A, over TT-E-485d, Type II)
B. Aluminum paint system (TT-P-486a, Type II and TT-V-81d, Type II, over TT-P-86a, Type I)
C. Oil paint system (TT-P-102a, Class A, over TT-P-86a, Type I)
D. Vinyl-alkyd system (MIL-P-15936B over MIL-P-15929B)

In addition to the panels with the resultant 20 coatings or coating systems, there was also prepared another set of coated steel panels without any zinc inorganic silicate primer, but with the vinyl-alkyd topcoat system applied over pretreatment primer. The former coating systems were designated 1, 2, 3, 4, 1A, 2A, 3A, 4A, 1B, 2B, etc.; the latter coating system was designated 5D. Coating thicknesses are shown in Table 1.

The panels employed were 6-x-12-inch hot-rolled steel plates. A set of four panels was prepared for each type of exposure and of these four panels, two panels were scribed and two panels were left unscribed, as shown in Figure 1.

The panels were rated at 6-month intervals. The results of the fourth rating, covering a period of two years, are shown in Table 2.

The ratings were assigned by NCEL personnel in accordance with ASTM standards, where applicable. A numerical rating was assigned for the degree of protection given by each coating; a rating of 10 indicated complete protection and a rating of 0 indicated no protection. Thus, for example, if the loss of protection to the metal substrate occurred over 10 to 20% of the panel surface, the coatings were given a rating of 8. When the protection rating reached 7 or less the panels were removed from the test.

Blistering was rated in accordance with ASTM Designation D714-56. The numerical ratings designate the blister size, ranging from 10, which indicated no blisters, to 2, which indicated blisters larger than 1/8 inch. Where blisters were larger than 1/4 inch a rating of 0 was given. The letter ratings designate the amount of blister formation, ranging from few (F) to medium (M), medium dense (MD), and dense (D).

Rusting of the unscribed panels was rated in accordance with ASTM Designation D610-43. A numerical rating of 10 indicated no rusting and lower numerical values indicated rusting in accordance with the photographic reference standards. Rusting at the scribed areas of the scribed panels was designated by a number and a letter. The number indicated the portion of the scribe mark that was not rusted, ranging from 10 for an unrusted scribe completely free from rust, to 0 for a scribe that showed no unrusted areas. The letter rating indicated the amount of rust deposited in the scribe which varied from light (L) to moderate (M) to heavy (H).

Undercutting indicates loss of adhesion, generally due to the formation of corrosion products under the coating films. This was rated light (L), occurring over less than 2% of the panels, medium (M), occurring over 2% to 10% of the panels, or heavy (H), occurring over more than 10% of the panel. This type of deterioration occurred along the scribe.

The ratings for each coating were tabulated, as shown in part in Table 2, and they were subjected to an analysis of variance.

DISCUSSION

It should be possible to speed up that portion of the deterioration of a coating which is primarily dependent on the amount of incident solar radiation by simply increasing the amount of solar radiation that is received. To obtain such increased radiation, complicated outdoor exposure apparatus which concentrates sunlight by means of mirrors has been developed and is used for testing coatings, plastics, and related materials. Other apparatus has been employed which will turn panels so that they face the sun throughout the day. Without complicated apparatus it is possible to increase the amount of radiation received on an exposed panel by choosing the optimum exposure angle. In temperate zones, the 45^{o} exposure angle, which is generally used for testing coatings, is such that nearly the maximum amount of available light is received on the panel. However in tropical locations, an appreciably increased amount of radiation would be obtained by lowering the angle of exposure to that of the latitude of the location.

At the equator, at noon, and at the equinox, the sun is directly overhead. Under this condition, a test specimen will receive the maximum amount of light when it is in a horizontal position and therefore perpendicular to the solar radiation. Similarly, as depicted in Figure 2, at any other location at noon and at the equinox, maximum radiation will be received when the panel is tilted from the horizontal by an angle equal to the latitude of the location, because in this position the panel will be normal to the solar radiation. If the exposure angle is changed from this position normal to the solar radiation, the radiation received will decrease by a factor which is the same as the cosine of the change in angle. Thus, at the equator, at noon, and at the equinox, a panel exposed at 45^{o} will receive only about 70% of the light received by a horizontal panel. Conversely, a 41% increase in the radiation received can be obtained by changing from a 45-degree exposure to a horizontal exposure. For some other locations the portions of available light received by a 45-degree exposure at noon and at the equinox are as follows:

Location	Latitude	Portion of available light received at 45-degree angle
Washington	39	.995
Port Hueneme	34	.982
Key West	24	.934
Kaneohe	22	.921
Kwajalein	9	.809
Equator	0	.707

The integration of the light received over each day of the year is very complicated,[1] but the ratio of the total amounts of light received by panels exposed at 45° and by panels exposed at the angle of the latitude are similar to the above values.

The importance of the orientation of panels in weathering tests, and the fact that the greatest radiation is received at an exposure angle which is the same as the angle of the latitude, had already been discussed by Walker in 1924.[2] More recently, it was found that lowering of the exposure angle to 15° in Florida did produce a noticeable difference in the deterioration of coatings after one year of exposure.[3] In oral communications with other scientists it became apparent that tests for automotive paints were being made in Florida at a 5-degree exposure angle because of the greater deterioration, that low exposure angles gave more rapid deterioration in the Canal Zone, and that low exposure angles produced more rapid deterioration in some Australian exposure.

An advantage to accelerating atmospheric exposure by lowering of the exposure angle would be that such accelerated deterioration would still occur in a natural environment and under exposures which would be encountered in practice. The most severe natural environment which would be encountered in practice would probably be the best for the testing of coatings.

The properties of coatings which are most rapidly affected by sunlight are probably chalking, loss of gloss, and color changes. These properties were therefore the ones that showed accelerated deterioration in low-angle exposures in Florida.[3] This acceleration was estimated to be about one or two months in a period of one year; that is, deterioration otherwise requiring one year required ten or eleven months. The changes in the coating which affect the above properties are primarily changes that occur near the surface of the coating. They are primarily changes in appearance rather than changes in the overall protection of the coating.

The appearance factors were of secondary importance in the NCEL evaluation of coatings, whereas the protective properties were of primary importance. The purpose of the present experiment was therefore to determine whether

increased solar radiation would not only cause more rapid deterioration of the coating surfaces, as had been shown by others, but whether it would also cause more rapid failure of the protective qualities of the coatings.

In the NCEL exposures at Kwajalein additional solar radiation on the panels could be obtained by facing the panels south, rather than east-northeast toward the sea and into the prevailing winds. As shown in the above table, a further increase of about 25% in solar radiation could be obtained by lowering the exposure angle. The solar radiation would thus be maximized and the deterioration caused or directly affected by solar radiation also should thus be maximized. The deterioration directly affected by the amount of salt spray or wind or particulate matter impinging on the panels might be somewhat reduced, but the 9-degree exposure angle would be so low that considerable spray would still hit the panel.

Advantage was taken of the opportunity to make the above comparative exposures when a series of coating systems was to be evaluated in the normal manner at Kwajalein. An analysis of the data obtained in two years of exposure indicates some increase in deterioration of the panels exposed at the lower exposure angle, as measured by the protective qualities of the coatings. However the results to date are not conclusive.

The two-year ratings of the 21 coatings or coating systems exposed at both 45° and 9° are shown in Table 2. In some instances deterioration was so rapid that failure occurred before the two-year exposure, and for these panels the comparisons are shown at 18 months or at 12 months.

Comparisons of the results of the 45° and 9° exposures are shown in Table 3. This table shows whether any of the rating factors listed in Table 2 indicate greater deterioration at 45° or at 9° or whether the deterioration was identical. Comparisons of unscribed panels and of scribed panels are listed separately.

The unscribed panels showed little deterioration in the two-year period, as measured by protection, blistering, and rusting ratings. Fourteen of the 21 systems on unscribed panels showed no such deterioration. Of the seven coating systems which did show some deterioration, four showed somewhat greater deterioration at 45°, and three showed somewhat greater deterioration at 9°. This difference is not significant.

All of the scribed panels showed some deterioration at the scribe, which at the very least became lightly rusted. Three of the systems showed identical ratings at 45° and at 9°. An additional four systems had one or more rating factors which indicated greater deterioration at 45°, and at the same time, one or more rating factors which indicated greater deterioration at 9°. Of the remaining 14 systems, five showed greater deterioration at 45°, as indicated by one or more ratings, and nine showed greater deterioration at 9° as indicated by one or more ratings. Thus, more of the systems showed increased deterioration at 9° than showed increased deterioration at 45°.

In addition to being subjected to the above analysis, the results were also subjected to an analysis of variance. As might be expected from the data in Tables 2 and 3, the analysis of variance was not able to show a definitely greater deterioration at the 9-degree exposure, nor did it show at this time any other conclusive information concerning 45-degree versus 9-degree exposures.

The evaluation of the above panels will continue and more conclusive comparative results should be available at a later date. The results to date indicate that, whereas increased irradiation is known to affect the appearance and surface qualities of coatings, it may have a lesser effect on the protective qualities of the coatings. There is also the possibility that the effect of greater irradiation was partly offset by the reduced salt spray and particulate matter provided by the southern exposure.

Increased solar radiation may have a proportionately greater effect on the protective properties of unscribed panels than on the protective properties of scribed panels. Photodegradation, and thermal changes should eventually deteriorate the organic topcoat and thereby affect the protective ability of the unscribed coating systems (and of areas away from the scribe). Protection at the scribed area is primarily dependent on the properties of the primer, provided the primer is suitably protected by a topcoat. Especially for an inorganic primer, the protective ability of the primer and of the scribed coating system may thus be affected less strongly by solar radiation. The comparative effect of increased radiation on the performance of unscribed panels cannot be determined until after these have deteriorated appreciably.

CONCLUSIONS

1. The results of two-year exposure tests indicate that the protective abilities of coatings might be evaluated somewhat more rapidly at Kwajalein by lowering the exposure angle from 45° to 9° from the horizontal.

2. No definite conclusions can be reached until further exposure data is obtained.

ACKNOWLEDGMENT

The assistance of Mr. A. F. Curry in the preparation and rating of the panels is greatly appreciated.

REFERENCES

1. W. D. Sellers. Physical Climatology. Chicago, The University of Chicago Press, 1965, pp. 33-35.

2. P. H. Walker. "Importance of position in weather tests," Industrial and Engineering Chemistry, 16, 528 (1924).

3. A. E. Pegis. "A study of the effect of angle of exposure on the exterior durability of air drying enamels," Official Digest, Federation of Societies for Paint Technology, 36, 1345-1347 (1964).

Table 1. Coating Thicknesses of the Various Systems

The thickness, in mils, of each coating and of each coating system are shown.

Topcoat System	Individual Coating	Zinc Inorganic Silicate Employed 1	2	3	4	None[a]
None	ZIS[b] (only)	2.5	3.0	4.0	2.5	
	Total	2.5	3.0	4.0	2.5	
A	ZIS	3.5	3.0	3.0	2.5	
	MIL-P-15328B	0.5	---	0.5	0.5	
	TT-E-485d	2.5	2.5	3.0	2.5	
	TT-E-489c	2.5	2.5	2.0	2.5	
	Total	9.0	8.0	8.5	8.0	
B	ZIS	2.5	3.0	2.5	2.5	
	MIL-P-15328B	0.5	---	0.5	0.5	
	TT-P-86a	1.0	1.0	1.0	1.0	
	TT-P-468c plus TT-V-81d	4.5	5.0	4.0	3.5	
	Total	8.5	9.0	8.0	7.5	
C	ZIS	2.5	3.0	4.0	2.5	
	MIL-P-15328B	0.5	---	0.5	0.5	
	TT-P-86a	1.0	1.0	1.0	1.0	
	TT-P-102a	5.0	4.0	3.0	5.5	
	Total	9.0	8.0	8.5	9.5	
D	ZIS	2.5	3.0	3.0	2.5	---
	MIL-P-15328B	0.5	---	0.5	0.5	0.5
	MIL-P-15929B	3.0	3.0	3.0	3.0	3.0
	MIL-P-15936B	3.0	3.0	4.0	3.0	3.5
	Total	9.0	9.0	10.0	9.0	7.0

a-System 5D is over bare steel.
b-Zinc inorganic silicate.

Table 2. Two-Year Ratings of Systems Exposed at 45° and 9°

System	Exposure Angle	Unscribed Panels[a]			Scribed Panels[a]				Notes
		Protection	Blistering	Rusting	General Protection	Blistering at Scribe	Rusting at Scribe	Undercutting at Scribe	
1	45	10	10	10	10	10	7L	10	
	9	10	10	10	10	10	OL	10	
2	45	4	10	4	4	OD	OH	M	
	9	8	10	8	7	2D	OH	M	
3	45	5	10	5	10	10	5L	10	b
	9	4	4D	4	10	10	5L	10	b
4	45	10	10	10	10	10	9L	10	
	9	10	10	10	10	10	9L	10	
1A	45	10	10	10	9	6MD	6L	10	
	9	10	10	10	9	6D	9L	10	
2A	45	10	10	10	7	2D	OH	M	c
	9	10	10	10	7	2D	OH	H	c
3A	45	10	10	10	10	8MD	7L	10	
	9	10	10	10	10	2F	OL	10	
4A	45	10	10	10	10	8MD	OM	10	
	9	10	10	10	10	8M	OL	10	
1B	45	9	2F	10	9	10	OM	10	
	9	10	10	10	10	6F	OM	10	
2B	45	10	10	10	9	2D	OH	10	
	9	10	10	10	8	2D	OH	10	
3B	45	10	10	10	10	4F	OL	10	
	9	10	10	10	10	10	OL	10	
4B	45	10	10	10	10	10	OL	10	
	9	10	10	10	10	8MD	OL	10	

Table 2. (Cont'd)

		Unscribed Panels[a]			Scribed Panels[a]				
System	Exposure Angle	Protection	Blistering	Rusting	General Protection	Blistering at Scribe	Rusting at Scribe	Undercutting at Scribe	Notes
1C	45	10	10	10	8	2D	OH	M	
	9	10	4F	10	8	4MD	OH	10	
2C	45	10	10	10	8	OM	6H	10	d
	9	10	10	10	7	OD	OH	H	d
3C	45	9	4MD	10	8	4D	10	10	
	9	9	2D	10	9	6D	9L	10	
4C	45	9	2F	10	9	4F	OM	10	
	9	10	10	10	10	8M	OL	10	
1D	45	9	4F	10	9	4MD	OM	10	
	9	10	10	10	9	4MD	OH	10	
2D	45	10	10	10	7	2D	OH	H	
	9	10	10	10	5	OD	OH	H	
3D	45	10	10	10	10	10	9L	10	
	9	10	10	10	10	10	9L	10	
4D	45	10	10	10	10	10	2L	10	
	9	10	10	10	10	10	OL	10	
5D	45	10	10	10	7	OD	OH	H	d
	9	10	10	10	8	OD	OH	H	d

Notes: a - The ratings are described in the text under "METHODS AND RESULTS."
b - Twelve-month ratings shown for unscribed and scribed panels.
c - Eighteen-month ratings shown for scribed panels.
d - Twelve-month ratings shown for scribed panels.

Table 3. Comparison of 45-Degree and 9-Degree Exposures

System	Unscribed Panels[a]			Scribed Panels[a]		
	Deterioration more severe at			Deterioration more severe at		
	45°	neither	9°	45°	neither	9°
1		X				R
2	R			PB		
3			PBR		X	
4		X			X	
1A		X		R		B
2A		X				U
3A		X				R
4A		X		BR		
1B	PB			P		B
2B		X				P
3B		X		B		
4B		X				B
1C			B	BU		
2C		X				PBRU
3C			B	PB		R
4C	PB			PR		
1D	PB					R
2D		X				PB
3D		X			X	
4D		X				R
5D		X		P		
21 systems	4	14[b]	3	5	7[b]	9

Notes: a - Exposure at which the ratings for protection (P), blistering (B), rusting (R), and/or undercutting (U) indicated greater deterioration, or where there was no difference in the ratings (X).

b - Systems showing no differences or showing greater deterioration for different factors at different exposures.

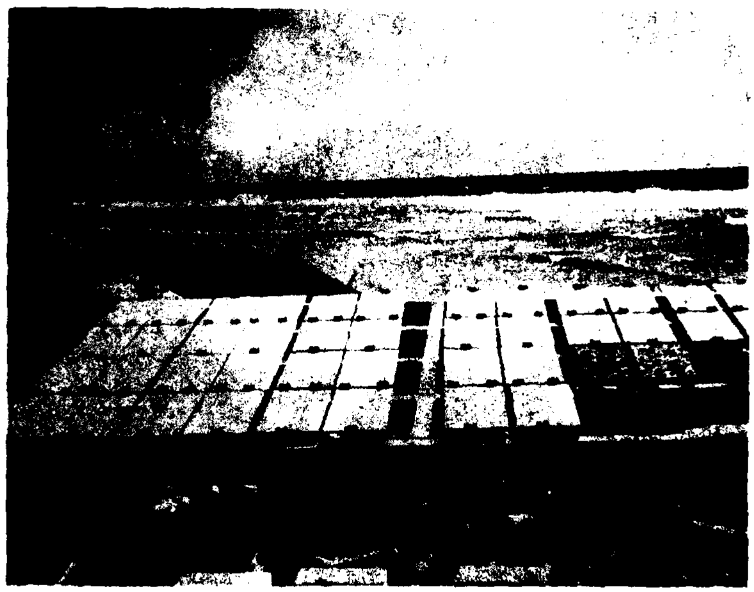

Figure 1. Exposure rack with coated panels

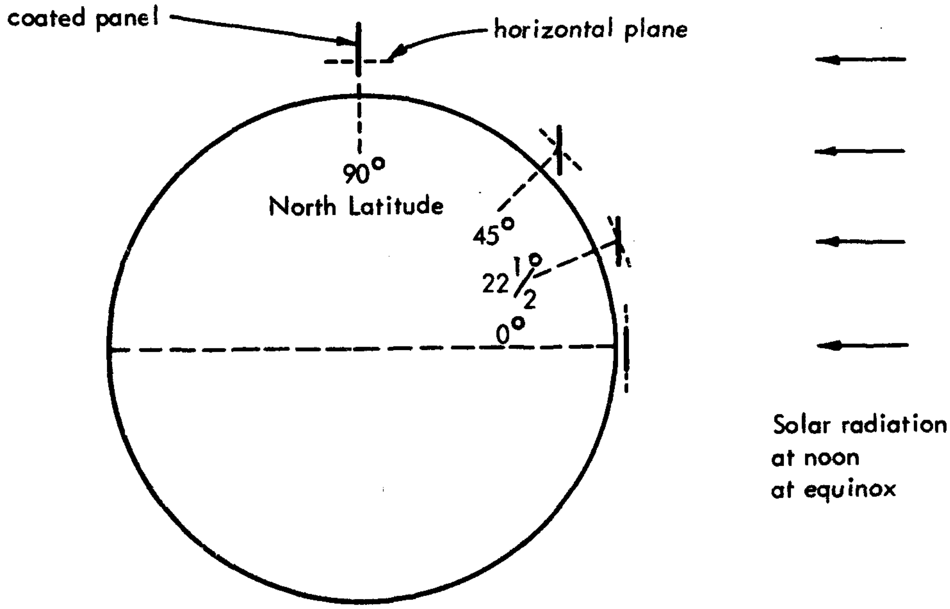

Figure 2. Exposure for maximum solar radiation

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13. ABSTRACT

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